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EVALUATION OF EXPLOSIVE BONDING FOR PATCHING ALUMINUM  
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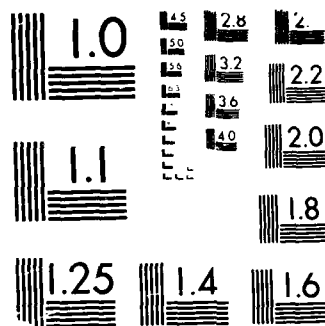
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**AD-A193 303**

# Evaluation of Explosive Bonding for Patching Aluminum With Aluminum

by  
Robert A. Weber  
Vonne Linsey

The U.S. Army Corps of Engineers maintains many waterborne vehicles and floating devices that are made of aluminum. Repair of these items usually involves gas metal arc welding a patch over the damaged area. However, the arc welding process is difficult to learn and is not well suited to use in the field. For these reasons, the U.S. Army Construction Engineering Research Laboratory (USA-CERL) has explored an alternative repair method—explosive bond welding.

Weld techniques using explosives are fairly well established, although most work in this area has involved the bonding of dissimilar metals. USA-CERL investigated the feasibility of welding aluminum to aluminum using explosive bonding.

Results of this study show that the 6061-T6 aluminum patch can be used effectively to weld patches onto both 5456 and 6061 aluminum alloys. Base plate thicknesses down to 0.125 in. can be welded and base plate deformation minimized when appropriate backup support is in place. The area covered by the patch can be varied by simply changing the size of the patch and the loop of explosive cord to fit the required dimensions.

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5456 and 6061 aluminum alloys commonly used in the items; must be safe and portable for use in the field; must require a minimum amount of explosives; the explosives(s) must already be in the Army inventory (and thus meet safety standards); and must include internal support or backups required for the wall thicknesses to be repaired.

Results of this study show that the 6061-T6 aluminum patch can be used effectively to weld patches onto both aluminum alloys. Base plate thicknesses down to 0.125 in. can be welded and base plate deformation minimized when appropriate backup support is in place. The area covered by the patch can be varied by simply changing the size of the patch and the loop of explosive cord to fit the required dimensions.

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## FOREWORD

This research was conducted for Headquarters, U.S. Army Corps of Engineers (USACE) under Project 4A162731AT41, "Military Facilities Engineering Technology;" Task B, "Construction Management Technology;" Work Unit 034, "Welding for Advanced Fastener Concepts."

The work was conducted by the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (USA-CERL). The USACE Technical Monitor was Mr. George Matsumura, CEEC-ED. Mr. Robert Weber was the USA-CERL Principal Investigator. Dr. Robert Quattrone is Chief of USA-CERL-EM.

Testing was done under contract by Mr. Vonne Linsey of the Metal Working Section, Battelle, Columbus Division, Columbus, OH.

COL Norman C. Hintz is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

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# **EVALUATION OF EXPLOSIVE BONDING FOR PATCHING ALUMINUM WITH ALUMINUM**

## **1 INTRODUCTION**

The Corps of Engineers has many aluminum items in its inventory, including water-borne vehicles and flotation devices. These items are subject to punctures that can compromise their watertightness. Corps personnel currently repair punctures by gas metal arc welding a patch over the hole, a difficult process that requires 6 months of initial training and up to a year of on-the-job skill improvement.

An alternative method of repair could be devised using explosive welding to apply an aluminum patch over the puncture. While explosive welding techniques are fairly well established for welding seams and cladding on flat plate, most of the work has been to develop procedures for welding dissimilar materials to provide transition joints for welding and corrosion protection. A patching procedure would require further development because it would involve only a loop of weld around the puncture, and some welds would be needed on a curved surface. There is concern that the molten jet formed by the explosive contact of the two surfaces would cut or gouge one of the curved surfaces, leaving a weakened structure or a hole. Another concern is how much support the area under the weld requires during the welding process in order to reduce the deformation of the base and patch plates and retard the rebound reaction until after the weld is completed. If a small enough charge could be used, a backup support might not be required.

If the explosive welding process proves feasible, it could be developed into a kit form, allowing quick repair with minimal training except for the safety aspects.

### **Objective**

The objective of this work is to determine the feasibility of using explosively welded aluminum patches to restore watertightness to damaged aluminum alloy structures.

### **Approach**

This experimental work was contracted to the Metal Working Section of Battelle, Columbus Division, Columbus, OH. Tests were conducted on both flat and curved surfaces to demonstrate the feasibility of applying the process to the surface geometries likely in field repair.

The explosive welding approach selected for the feasibility demonstration included consideration of the following:

- Existing explosive welding technology was to be adapted to this specific application.
- The patch material and explosive parameters (explosive type, loading, and standoff) were to be selected so that a single repair system would be applicable to both the 5456 and 6061 aluminum alloys commonly used in the vehicles.

- The internal support or backup requirements during welding were to be established for the wall thicknesses being repaired.

- The repair system was to be designed so it would be safe and portable for easy application under field conditions.

- The quantity of explosive in the system was to be minimized for field practicality.

- The explosives (including the detonator) selected for the system were to be standard materials currently used in the military, therefore meeting the required safety standards.

The approach selected for explosive welding the patches employs a cord type of explosive known as Primacord\*, which produces a narrow strip or seam weld between the cover sheet (patch) and the base onto which it is being welded. The basic feasibility of this technique for seam welding thin sheets of aluminum and steel to thicker bases was demonstrated at Battelle more than 15 years ago. It is a simple process that is capable of seal welding the periphery of an area with a minimum quantity of explosive.

#### **Mode of Technology Transfer**

It is recommended that the information in this report be used to prepare a puncture repair system to be used by Corps personnel. Use of the system would be described in Technical Manual 5-210, *Military Floating Bridge Equipment*.

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\*"Primacord" is a product of Ensign-Bickford Co.

## **2 TEST PROCEDURES**

### **Materials**

The patch or cover sheet material selected for the repair procedure was 0.062 in.-thick\* 6061-T6 aluminum sheet. It was determined that this material would provide sufficient strength to seal against the ambient water pressure. The aluminum alloy base materials and thicknesses used in the study were:

- 0.125 in. 6061-T6
- 0.250 in. 6061-T6
- 0.250 in. 5456.

This range of thicknesses is broader than might be encountered for actual repair.

### **Determination of Parameters**

A preliminary series of simple strip welding experiments was conducted to select the critical explosive welding parameters for achieving a high integrity weld with the 0.062 in.-thick cover sheet. The tests consisted of making a simple linear weld down the centerline of 1.5 in.-wide by 6.0 in.-long flat samples of the cover sheet and a 0.25 in.-thick 6061-T6 base. These experiments were done to determine the following primary parameters required to yield a high integrity weld:

- The loading (grains per foot) of explosive cord
- The initial separation or standoff distance
- The allowable variation in separation distance between the cover sheet and the base.

The weld integrity was evaluated by chisel testing to determine if the weld could be separated by peeling.

### **Small Patch Welding**

The optimum welding parameters determined in the strip weld tests were used in making three small circular patch welds having a nominal diameter of 4.5 in. The welds were made with 6 in.-square 0.062 in.-thick 6061-T6 patch plates, and 0.125 and 0.250 in.-thick 6061-T6 and 0.250 in.-thick 5456 base plates. The back surfaces of the base plates were supported with 2 in.-thick styrofoam resting on a steel anvil to provide moderate support. Following welding, the area sealed by the ring weld under the patch in each sample was pressurized to 10 psi with air through a predrilled and tapped hole in the base, and then checked for leaks while the sample was held under water.

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\*1 in. = 25.4 mm.

### **Extended Patch Welding**

The next series of experiments involved expanding the size of the patch weld to cover a 4.0 by 8.0 in. oval area on a flat surface. These tests were conducted on 0.250 and 0.125 in.-thick 6061-T6 aluminum base plates. The parameters established in the strip weld tests were used. Some of the base plates were supported by styrofoam, water, or neoprene rubber; others were left unsupported. Each weld was leak tested to a pressure of 10 psi\*.

### **Curved Surface Welding**

The final experiment was conducted to demonstrate the feasibility of explosive welding a patch to a curved surface similar to that which would be encountered in the field. A 0.250 in.-thick 6061-T6 aluminum base plate and a 0.062 in.-thick matching patch were formed to a nominal 4 in. radius. One-half-inch-thick neoprene rubber was used to support the curved base plate. The parameters established in the strip weld tests were used. The finished weld was leak tested to 10 psi.

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\*1 psi = 6.89 kPa

### 3 RESULTS AND DISCUSSION

#### Preliminary Strip Welding

The results of the preliminary strip weld experiments showed that the 0.062 in.-thick 6061-T6 aluminum alloy cover sheet could be successfully welded to the base with 50 grain/ft explosive cord and a separation distance ranging from 0.032 to 0.062 in. Optimum standoff distance for this explosive loading is 0.045 in. The explosive cord was initiated with a standard No. 8 electrical detonator or blasting cap. A strip weld made at these optimum conditions and after chisel testing is shown in Figure 1\*. The cover sheet failed around the weld, leaving the weld intact. It was also found that the explosive cord required a backing material to cover it and the patch plate. Plaster of paris was found to be a good choice for this because the powder is readily available and can be poured into any shape.

#### Small Patch Welding

The total quantity of explosive required to make each of these welds was 4.1 grams, not including the detonator. No leaks were found in the three samples, which indicated complete sealing by the explosive welding process for both the 6061-T6 and 5456 alloys and for both the 0.125 and 0.250 in.-thick bases supported on steel-backed styrofoam. The total depth of deformation of the base plate into the styrofoam backing support for each sample is shown in Table 1.

Table 1  
Depth of Deformation

Alloy	Base Plate Thickness, in.	Depth Deformation, in.
6061-T6	0.125	0.281
6061-T6	0.250	0.061
5456	0.250	0.125

The deformations encountered were greatest directly under the explosive cord. As expected, the 0.125 in. base plate sample sustained the most extensive deformation during welding, while the 0.250 in. 6061-T6 base plate was deformed less than the same thickness of 5456 base plate. The sample with the 0.250 in.-thick 6061 base plate is shown in Figure 2.

#### Extended Patch Welding

The 50 grain/ft explosive cord (6.5 grams total) and a nominal 0.045 in. standoff was used for this work. The detonator was placed at one end of the oval. Figure 3 shows the explosive cord in place over the patch plate. Figure 4 shows the assembly ready for detonation with the plaster of paris in place. The first of these extended patch weld experiments was made with the base plate again resting on a 2-in.-thick styrofoam backing. The welded plate is shown in Figure 5. The 0.250 in. aluminum base plate

---

\*Figures are shown at the end of the chapter.

showed very little deformation after welding: the total depth of deformation was less than 0.032 in. The patch weld was found to be completely sealed at the 10 psi test pressure.

The next two experiments were conducted without any backup support to determine the degree of support, if any, necessary to achieve welding and to keep the base from deforming to the point where the weld could not be effected or tearing occurred. Figure 6 shows one set-up ready for detonation. One experiment was conducted on a standard 0.250 in.-thick 6061-T6 aluminum base plate while the other was conducted on a 0.125 in.-thick 6061-T6 aluminum base plate. The patch on the unsupported 0.250 in.-thick base plate was only partially welded while the one on the 0.125 in.-thick base was completely unwelded. Examination of the weld areas revealed that the required jetting and wave formation for explosive welding had occurred during the collision; however, the unsupported base plates had responded to the welding impact before the weld could be effected. This was further indicated by the significant deformation that occurred in the base plates: a depth of 0.250 in. for the 0.250 in. plate and 1 in. for the 0.125 in. plate. These results indicate that aluminum base plates at least up to 0.250 in. thick require auxiliary backing support in order to achieve welding and to minimize base plate deformation. The success of the experiments with styrofoam backing, however, indicates that the amount of support required would not have to be prohibitive in terms of required mass or response time.

The next experiments in the series were to determine the most appropriate method of supporting the base component. The primary considerations in selecting a technique for supporting the base material on the interior surface were the limited accessibility to the interior to apply the support material and the assumption that the support material would have to remain following patching, since there would be no access to the interior to remove it. On this basis, water and neoprene rubber were selected for further investigation. The approximate minimum thickness required for each backup material was calculated based on the density and acoustic impedance match to the aluminum it was supporting. The intent was to provide the equivalent of an additional 0.250 in. of aluminum. The minimum thicknesses were estimated to be 1 in. for the water and 0.50 in. for the neoprene rubber. For these tests, a plastic bag was filled with water, and the test piece was laid on top of it (Figure 7). The same set up was used for the neoprene.

Expanded patch welds on 0.250 in.-thick 6061-T6 aluminum base plates supported with each of these materials yielded leaktight welds with less than 0.062 in. deformation of the base plates. Figure 7 shows the test plate supported by a bag of water ready for detonation, and Figure 8 shows the sample supported with neoprene rubber.

A third support experiment was then conducted with a 0.125 in.-thick 6061-T6 base plate supported with 0.50 in. neoprene. After detonation, it was also found to be leak tight. Its deformation depth was 0.125 in. as shown in Figure 9.

### **Curved Surface Welding**

A 4 by 8 in. oval explosive patch weld was made to the base with almost no deformation of the base (Figure 10). The weld was found to be leak tight. There was some concern about the jet produced by the explosive contact burning holes or cutting slots in the patch plate because of the curvature. This did not occur in the test, probably because the explosive energy is very low with this system, and the jet would have a very low energy as well.

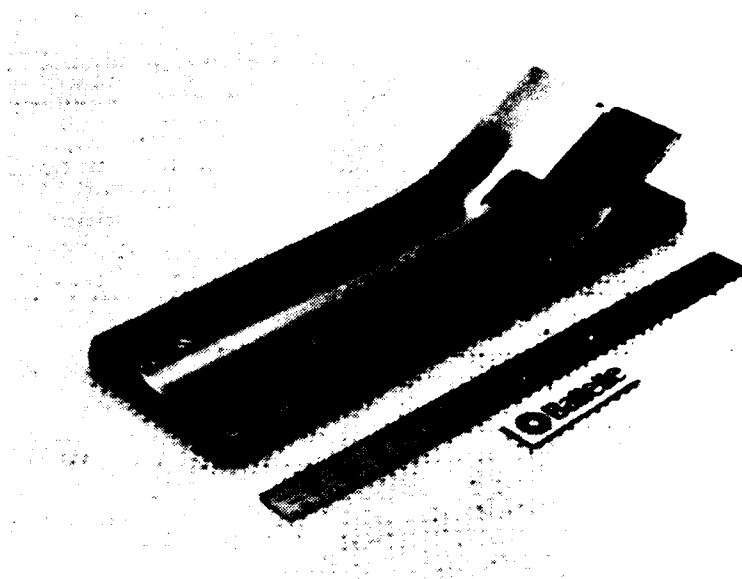


Figure 1. Linear strip weld made with optimum explosive welding conditions.

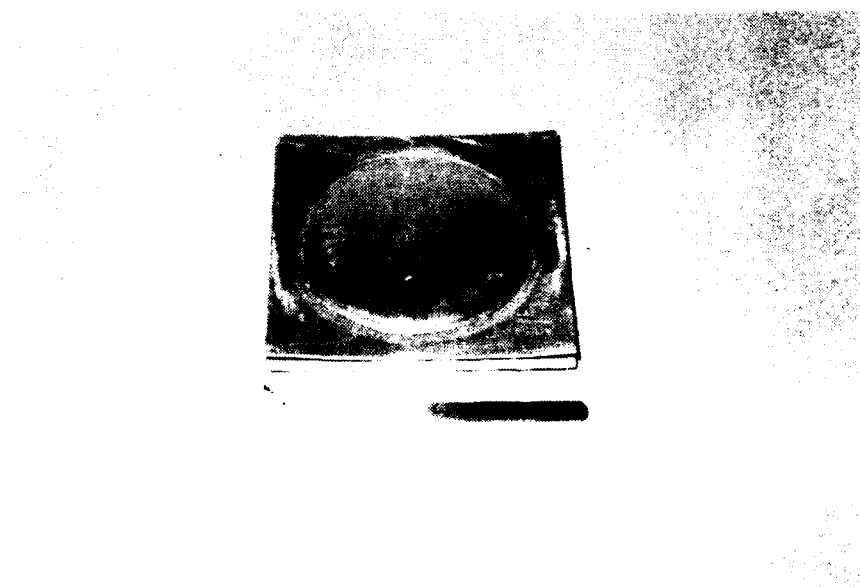


Figure 2. Circular explosive patch weld on 0.025 in.-thick 6061-T6 aluminum base plate.

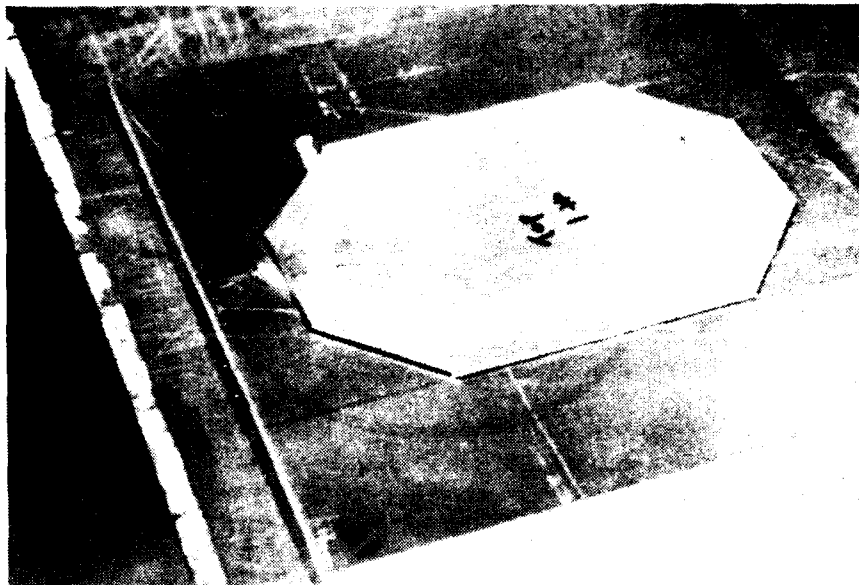
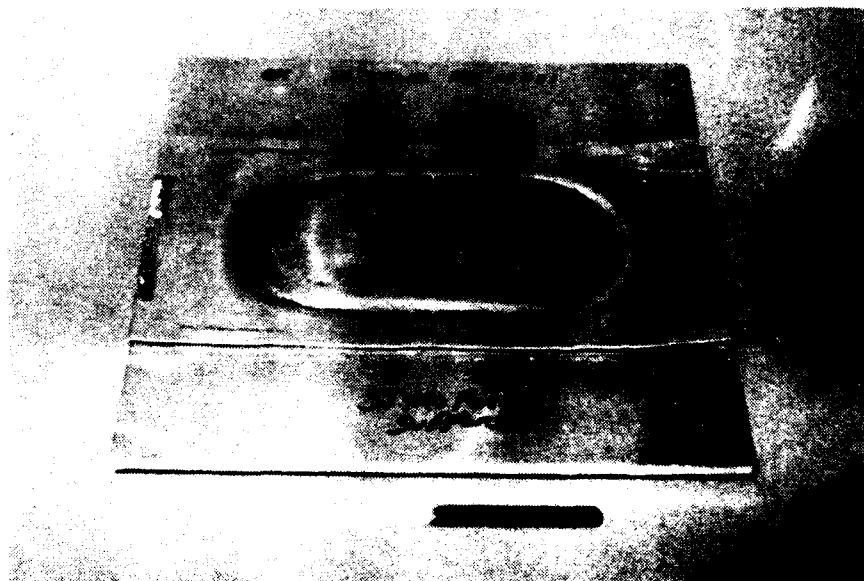


Figure 3. Extended patch setup showing explosive cord in position.



Figure 4. Extended patch weld with the plaster of paris in place ready for detonation.



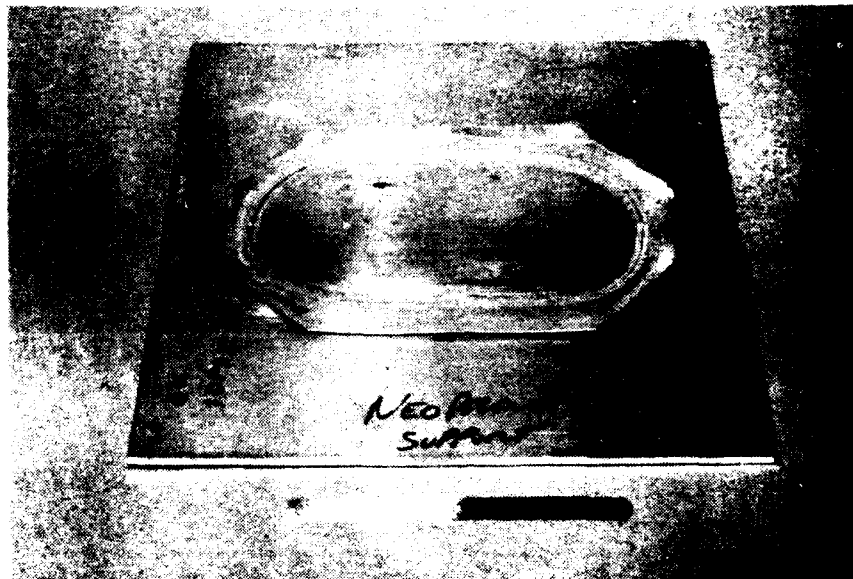
**Figure 5. Pressure tested explosive patch weld on 0.250 in.-thick 6061-T6 aluminum base plate with styrofoam backup support.**



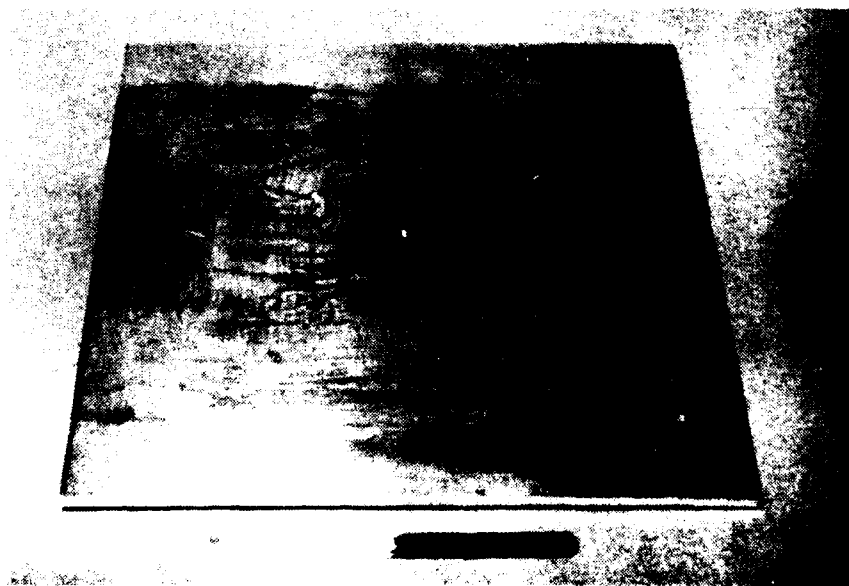
**Figure 6. Explosive patch setup with no backup support.**



**Figure 7. Extended patch weld on 0.250 in.-thick 6061-T6 base plate supported by water as the backup.**

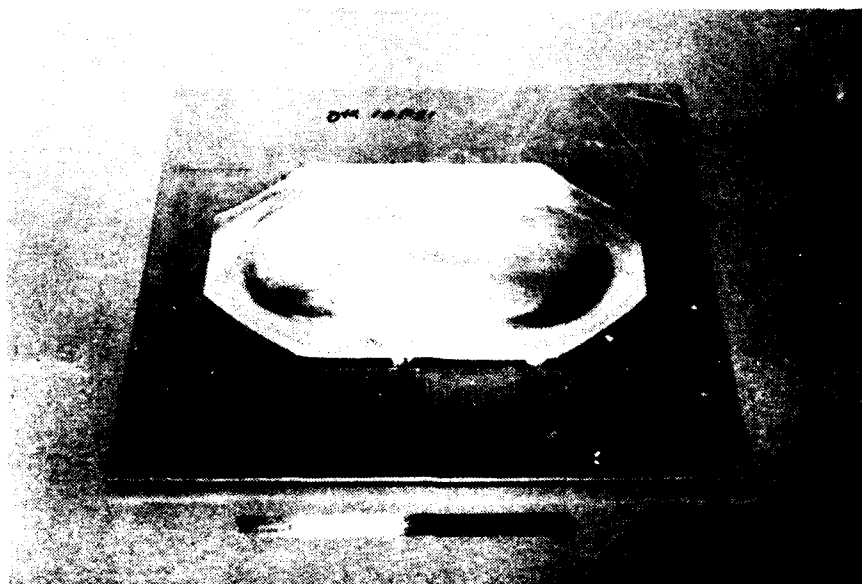


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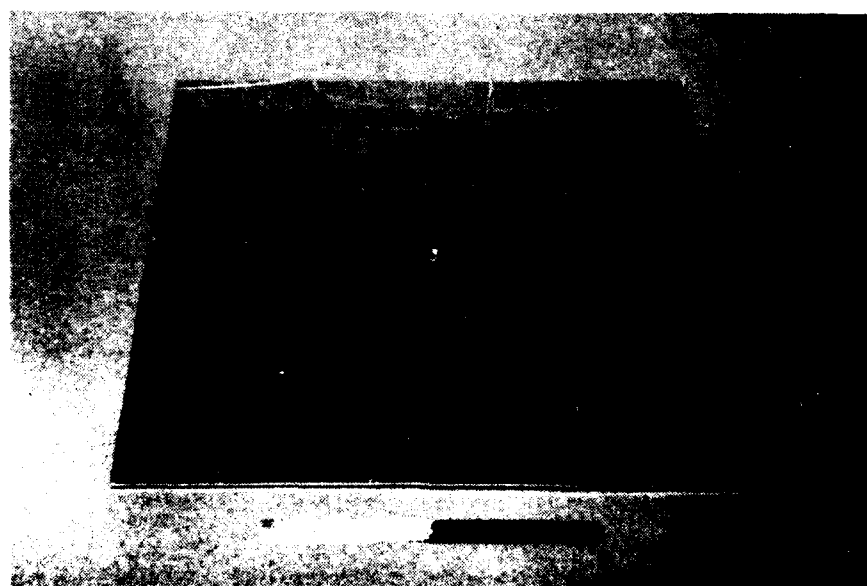


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Figure 8. Sample of 0.250 in.-thick 6061-T6 aluminum base plate supported with 0.50 in.-thick neoprene rubber. (a) Front side and (b) back or supported side.



(a)

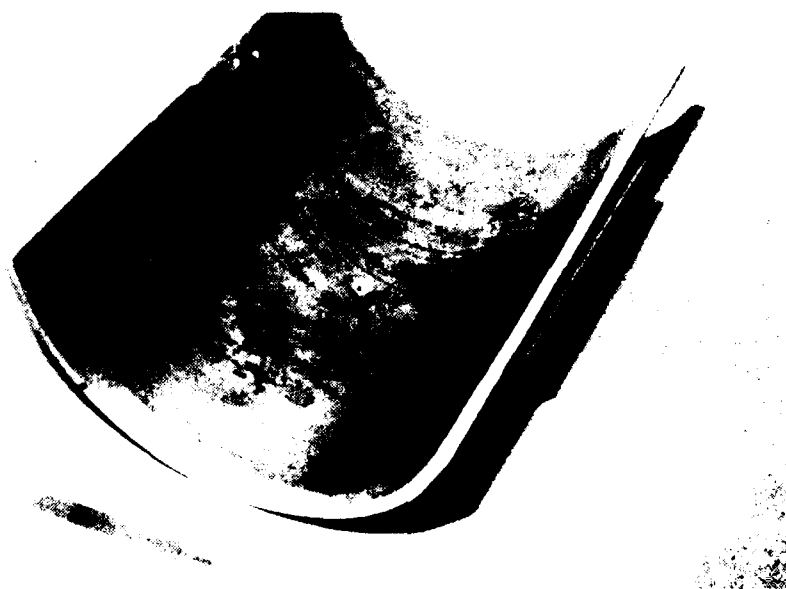


(b)

Figure 9. Sample of 0.125 in.-thick 6061-T6 aluminum base plate supported with 0.50 in.-thick neoprene rubber. (a) Front side and (b) back or supported side.



(a)



(b)

**Figure 10.** Explosive patch weld on curved 6061-T6 aluminum base plate. (a) Front side and (b) back or supported side.

#### 4 CONCLUSIONS AND RECOMMENDATIONS

The results of this study have demonstrated the feasibility of using explosively welded aluminum patches to restore watertightness to damaged aluminum alloy structures.

The explosive patch weld system developed in this study uses existing explosive welding technology and standard military explosives (50 grain/ft explosive cord and standard No. 8 strength detonators). The quantity of explosive required has been minimized for field practicality. For example, the extended patch weld which covered an oval area 4 by 8 in. required a total of 6.5 grams of explosive, including the detonator.

Tests results showed that:

1. The 6061-T6 aluminum patch can be welded onto either a 6061-T6 or 5456 alloy aluminum base, allowing the potential for a single repair system.

2. Base plate thicknesses down to 0.125 in. can be welded and base plate deformation minimized with the use of appropriate backup support. This support can be a layer of either neoprene rubber or water, both of which can be applied in the field with relative ease. Base plate thicknesses at least up to 0.250 in. were found to require this auxiliary backup support.

3. The overall size of the area covered by the patch can be varied by simply changing the size of the patch and the loop of the explosive cord to fit the required situation.

The approach developed in this study shows potential for implementation as a portable, safe unit under field conditions.

It is recommended that a portable field unit be designed and deployed to include explosive cord, backing material for the base plate, backing material for the cord, detonators, and cardboard to hold the backing material for the cord.

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